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ORIGINAL ARTICLE

Cancer mortality in a Swedish cohort of pulp and paper mill workers

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Abstract
Purpose To study cancer mortality among Swedish pulp and paper mill workers by main mill pulping process and department, and to present the Swedish part of an international exposure measurements database.
Methods A cohort of 18,163 male and 2,290 female workers at four sulfate and four sulfite mills, enrolled from 1939 to 1999, was followed up for mortality during 1952–2001. Standardized mortality ratios (SMRs) relative to the general Swedish population were calculated.
Results There were 1,340 malignant cases out of 5,898 deaths. Total cancer mortality was not increased in either sulfate or sulfite mill workers, or by gender. Lung cancer mortality was increased among female workers (SMR 1.70, 95% CI 1.04–2.63), especially in paper production, but not among male workers (SMR 0.91, 95% CI 0.79–1.04). Exposure to wood dust and sulfur dioxide frequently exceeded occupational exposure limits.
Conclusions Female paper production workers had an increased mortality from lung cancer.

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Keywords Exposure database · Lung cancer · Sulfate pulping · Sulfite pulping

Introduction

Pulp and paper production involves a large number of chemical agents, and worker exposure to these agents varies widely between processes and departments. The main occupational exposures in focus have been wood dust and paper dust, terpenes and bleachery chemicals, sulfur dioxide, hydrogen sulfide, and various reduced sulfur compounds and paper additives (Torén et al. 1996a). Furthermore, among the multitude of chemicals used in this industry, some potential carcinogens also occur across different departments, such as wood dust, organic solvents, chloroform, mineral oil mist, asbestos, benzo(a)pyrene, respirable quartz, epichlorohydrin, formaldehyde, chromium, and nickel (Kauppinen et al. 2002; Teschke et al. 1999; Korhonen et al. 2004).

The International Agency for Research on Cancer (IARC) carried out a collaborative epidemiological study within the pulp and paper industry, and an international database of exposure measurements in the pulp and paper industry was created as part of that project (Kauppinen et al. 1997). Detailed exposure data associated with paper production (Korhonen et al. 2004) and non-production departments collected in this study have been published (Teschke et al. 1999). Exposure measurement time trends resulting from compliance inspections in the US pulp and paper industry have also been published (Coble et al. 2001). However, pulp production data gathered in the IARC study have not yet been published. Furthermore, the Swedish part of the overall IARC database comprised 12% of the total measurements, and 20% of the measurements associated with pulp production. Hence, these data are of significant potential interest, and thus are presented here (Kauppinen et al. 1997).

In a review of malignancies in the pulp and paper industry, lung cancer, probably related to asbestos exposure, and malignant lymphomas have been associated to such employment (Torén et al. 1996b). In addition, further mortality studies have suggested links between employment in this industry and several other malignancies, such as leukemia and cancers of the kidney, pleura, and prostate (Torén et al. 1996b; Band et al. 1997; Matanoski et al. 1998). Some Swedish and North American studies have also reported an associated increase in brain tumor mortality (Band et al. 1997; Matanoski et al. 1998; Andersson et al. 1998, 2001, 2002). Some studies have also found that risks of stomach cancer, possibly associated with sulfite pulping, may be increased by employment in the industry (Wingren et al. 1985; Torén et al. 1996b; Band et al. 1997, 2001). Furthermore, exposures to sulfur dioxide as well as sulfite pulping have been associated with increased mortality from lung cancer among pulp mill workers (Henneberger and Lax 1998; Lee et al. 2002).

The data presented in this article were obtained from a cohort study of four sulfate and four sulfite mills that examined main mill pulping process and department specific mortality and morbidity among Swedish pulp and paper mill workers (Andersson et al. 2007). As many past cancer studies in pulp and paper mills were mortality studies, we present mortality data for malignant causes. The cancer incidence data will be analyzed separately and presented elsewhere.

The main aim was to study cancer mortality by pulping process and in department in pulp and paper mill workers. Our specific questions were whether increase in brain tumor mortality occurred at any department and whether sulfite pulping was associated with increased lung or stomach cancer mortality. In addition, air concentration data from the database were used to explore the exposure to chemical agents in general and carcinogens in particular.

Subjects and methods

The cohort consisted of 20,453 male and female workers from eight pulp and paper mills located in various, mostly rural, parts of Sweden (Table 1). A more extensive description of the cohort can be found in Andersson et al. (2007). Three of the mills are included in the IARC study. An overall inclusion criterion for the employees was more than one year of employment in the mill. Information on the employees' name, date of birth, unique personal identification number, date of employment, date of termination (if applicable), and work history (job titles and/or departments) were collected from the personnel files at the mills. However, from one mill workers who had worked solely between 1965 and 1968 were missing. Workers ($n = 265$) for whom dates of their employment periods were incomplete were excluded. Median employment duration was 12 years (range 1–60 years), median year of employment was 1967 (range 1893–1999), and median age at employment was 24 years (range 7–69 years). The cohort included 137 subjects who had worked in more than one mill.

Table 1 Distribution of subjects in the cohort of Swedish pulp and paper mill workers

	Sulfate mills		Sulfite mills		Total
	Males	Females	Males	Females	*N* (%)
Duration of employment					
1–5 years	3,085	388	2,224	435	6,132 (30.0)
>5–10 years	1,646	237	1,103	204	3,190 (15.6)
>10–20 years	2,305	362	1,668	231	4,566 (22.3)
>20–30 years	1,447	208	1,320	123	3,098 (15.1)
>30 years	1,617	54	1,748	48	3,467 (17.0)
All included	10,100	1,249	8,063	1,041	20,453 (100)
Calendar period, employed years					
Before 1940	36,734	224	41,321	643	78,922 (24.8)
1940–1949	17,187	1,401	25,251	1,085	44,924 (14.1)
1950–1959	26,131	2,347	14,614	984	44,076 (13.8)
1960–1969	28,023	4,328	19,191	1,916	53,458 (16.8)
1970–1979	32,018	4,615	24,673	3,425	64,731 (20.3)
1980–1999	13,730	2,054	14,392	2,432	32,608 (10.2)
All employed years	153,823	14,970	139,443	10,486	318,722 (100)
Person-years of follow-up					
All person-years	284,043	36,033	222,968	26,650	569,694

Distributions given by main mill pulping process, gender, and duration of employment, as well as employed years by main mill pulping process, gender and calendar periods. Person-years of follow-up are also included

The Swedish national Causes of Death register was begun in 1952, and hence either that year was used as the follow-up start date or, if an employee started their work later, the year of first included employment. The end of the follow-up period was determined as the one of the following whichever came first: death, emigration, or last observed date. Vital status was determined for all of the cohort members at the end of the follow-up period, with 14,232 individuals alive, 324 emigrated, and none lost to follow-up. The total number of person-years of follow-up was 569,694, while total mill employment comprised 318,722 years (Table 1). The cohort was also linked to the national Causes of Death register. The causes of death are given in accordance with the 9th revision of the International Classification of Diseases (ICD 9). The study was approved by the Ethical Committees in Göteborg (Dnr Ö 290-00) and Uppsala (Dnr 2004:M-21).

Exposure assessment

Detailed department and job titles were defined, where available, for each period of employment for each worker according to the coding used in the IARC international study. They were also merged into larger entities, which are here defined as departments. The departments were wood preparation (including wood preparation and ground wood pulping), sulfite pulping, sulfate pulping, paper production (including paper and paperboard production, and manufacture of paper and paperboard products), maintenance and repair, and office work. The data were then analyzed by main mill pulping process, gender, and department. Furthermore, one subject could contribute person-years to more than one department, with 1,446 subjects employed at two different departments and 125 at three or more. However, in each analysis, a worker is only counted once. The cohort also included workers from departments other than those listed above, and workers for whom job task information was not available. These workers were placed in an "other departments" category. Female workers who were employed in departments other than paper production and office work were also analyzed under the category of "other departments". In addition, data on workers in some smaller departments of interest, such as the bleachery and steam and power generation departments were also analyzed.

The Swedish part of the IARC database for the pulp and paper industry was also collected as part of this cohort project, including 3,792 air measurements for the period from 1971 to 1991. Data on 43 different chemical substances and biological agents were collected from 32 Swedish pulp and paper mills. Data on air concentrations of chemical and biological agents are presented (Table 2); the number of samples, arithmetic means (AMs), standard deviations (SDs), ranges, geometric means (GMs) and their corresponding standard deviations (GSDs) are also given.

Statistical analysis

Person-years at risk were calculated and stratified according to gender, five-year age groups, and one-year calendar periods. As a reference, the general Swedish population was used to calculate the expected number of deaths. In addition, we compared the data for total cancer mortality against the Swedish population with the three main cities excluded, based on information from 1970 to 2001. Standardized mortality ratios (SMRs) with 95% confidence intervals (CIs) were calculated assuming a Poisson distribution. Estimates of risk with regard to main mill pulping process, department, gender, and duration of employment were also calculated. The analyses were performed using the computer program STATA (STATACorp 2005).

Results

There were 5,898 deaths among the cohort during the study period between 1952 and 2001, and 1,340 of these were due to malignancies. The overall mortality rate in the cohort was lower than in the Swedish reference population, with an SMR of 0.97 (95% CI 0.94–0.99), and the total cancer mortality was not increased, with an SMR of 0.95 (95% CI 0.90–1.00).

The Swedish part of the IARC exposure measurement database departmentwise are presented (Table 2). Some of the exposures are potentially carcinogenic. The Swedish wood dust occupational exposure limits (OELs) of 2 mg/m^3 was surpassed in 30% of the samples from wood preparation areas. In the sulfite pulp production departments, 50% of the measured sulfur dioxide concentrations were far higher than the OEL of 5 mg/m^3, ranging up to 232 mg/m^3, and most of the high air levels were found during the digestion operations. The levels of chloroform, a chemical agent considered to be a carcinogen, exceeded the Swedish OEL of 10 mg/m^3 in 10% of the samples from the sulfate pulping departments, with a highest level of 120 mg/m^3. In addition, mercury exposure during chlorine production has been historically extensive, and concentration levels of 0.12 mg/m^3 were found in the database; substantially higher than the OEL of 0.01 mg/m^3. Moreover, a number of carcinogens were recognized in the paper production departments, although asbestos and benzo(a)pyrene were detected at lower concentration levels than their respective OELs. However, some determined concentrations of silica-containing dust, epichlorohydrin, and formaldehyde were higher than their respective OELs. Asbestos, chromium, and nickel were also found in the maintenance and repair departments, although at concentrations below their respective OELs.

Specific estimates of cancer mortality by gender for the main mill pulping processes are presented in Table 3. Lung

Table 2 Air sample concentrations (mg/m^3) of chemical and biological agents in the Swedish part of the database of exposures in the pulp and paper industry by department, 1971–1991

Agent air concentrations mg/m^3	Samples *N*	AM	SD	GM	GSD	Range
Wood preparation						
Dust	39	1.9	2.7	0.93	3.4	0.1–15
Endotoxins[a]	48	0.067	0.17	0.018	5.9	0.00028–1.2
Fungal spores[b]	19	8600	6600	1500	61	0.001–19000
Hydrogen sulfide	17	0.0225	0.021	0.018	1.9	0.008–0.096
Terpenes	292	253	570	57	6.2	0.12–4235
Wood dust	46	2.1	2.6	1.2	2.8	0.3–15
Sulfite pulping						
Sulfur dioxide	1,192	10.2	15	4.7	6.5	0.003–232
Sulfate pulping						
Acetone	2	10	12.1	5.95	5.1	1.9–19
Calcium oxide	55	4.8	8.2	0.91	9.7	<0.01–48
Chloroform	81	24	26	10	7.3	<0.05–120
Chlorine	331	1.3	7	0.1	12	<0.004–88
Chlorine dioxide	314	0.33	0.77	0.088	5.5	<0.004–8.3
Dimethyl disulfide	52	5.4	17	0.38	7.3	<0.003–77
Dimethyl sulfide	52	5.1	16.2	0.46	6.4	<0.039–92
Dimethyl trisulfide	11	0.006	0.0121	0.006	1.2	<0.003–0.009
Dust, total	79	3.6	7.9	1.5	3.7	<0.6–64
Dust, organic	2	120	92	95	2.5	50–180
Hydrogen sulfide	29	33	81	0.11	72	<0.06–278
Mercury	32	0.0066	0.021	0.00062	9.9	0.0001–0.12
Mercaptanes	15	0.94	0.78	0.28	21	0.0002–3
Methyl mercaptanes	12	0.164	0.32	0.088	2.3	<0.05–1.2
Oil mist	1	0.13		0.13		0.13–0.13
Sulfur dioxide	9	19	26	1.9	51	0.0026–78.9
Styrene	18	161	152	10.0	3.2	5.2–521
Terpenes	13	2.1	6	0.38	5	0.034–22
Paper production						
Asbestos	13	0.071	0	0.071	1	<0.1–0.071
Benzo(a)pyrene	86	0.001	0.0027	0.00039	4.7	<0.00005–0.019
Carbon monoxide	4	0.0001	–	0.0001	–	0.0001–0.0001
Dust (silica-containing)	10	7.6	12	3.4	3.6	0.8–39
Dust, total	201	5.7	7	2.6	4.2	<0.06–55
Endotoxins	6	0.016	0.012	0.012	2.2	0.004–0.038
Epichlorohydrin	14	5.8	8	1.1	9.6	<0.01–24
Formic acid	1	0.066	–	0.066	–	0.066–0.066
Formaldehyde	271	3.3	10.3	0.27	12	<0.06–62
Ammonia	24	4.7	7.6	0.69	29	<0.5–35
Nitrogen dioxide	4	7.6	3.4	7	1.6	4–12
Dust, organic	8	0.47	0.33	0.37	2.1	0.13–1.1
Dust, paper	148	0.63	0.7	0.41	2.5	0.07–4.4
Dust, respirable	8	0.55	0.053	0.55	1.1	0.5–0.6
Sulfur dioxide	4	9.2	4.5	8.4	1.7	5.2–13
Maintenance and repair						
Acetone	9	43	45	31	2.2	10–155
Asbestos	4	0.071	0	0.071	1	<0.1–0.071
Chromium	6	0.081	0.150	0.0044	2.1	0.0003 – 0.380

Table 2 continued

Agent air concentrations mg/m^3	Samples *N*	AM	SD	GM	GSD	Range
Dust, total	13	4.6	7.6	1.1	5.8	<0.3–26
Dust, organic	7	4.2	6.6	2	3.5	0.4–19
Dust, silicates	3	9.7	17	0.2	75	0.012–29
Manganese	3	0.0017	0.00058	0.0016	1.5	0.001–0.002
Nickel	6	0.024	0.044	0.0026	12	<0.001–0.110
Oil mist	5	0.8	0.52	0.7	1.8	0.4–1.7
Styrene	27	70	78	34	4.1	2.2–313
Steam and power generation						
Hydrogen sulfide	11	3.2	1.1	0.67	2.5	0.27–3.1
Sulfur dioxide	10	1.1	0.32	1.1	1.3	0.66–1.6

AM arithmetic mean, *SD* standard deviation, *GM* geometric mean, *GSD* geometric standard deviation, *OEL* occupational exposure limit

[a] μg/m^3; [b] cfu/m^3

Table 3 Overall and cancer mortality among Swedish pulp and paper mill workers

Cause of death (ICD-9)	Sulfate mills males (*n* = 10,100)			Sulfate mills females (*n* = 1,249)			Sulfite mills males (*n* = 8,063)			Sulfite mills females (*n* = 1,041)		
	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI
All causes	2,875	1.02	0.98–1.06	202	0.93	0.81–1.07	2,664	0.93	0.90–0.97	157	0.86	0.73–1.00
All malignancies (140–208)	631	0.98	0.90–1.05	62	0.92	0.70–1.18	595	0.93	0.85–1.00	52	1.00	0.74–1.30
Stomach (151)	57	0.97	0.73–1.25	2	0.62	0.07–2.22	67	1.07	0.83–1.36	3	1.05	0.22–3.06
Intestine (152–154)	85	1.09	0.87–1.35	7	0.91	0.37–1.87	69	0.88	0.69–1.12	2	0.32	0.04–1.16
Pancreas (157)	46	1.09	0.80–1.45	9	2.03	0.93–3.85	32	0.77	0.52–1.08	3	0.86	0.18–2.52
Lung, bronchus and pleura (162, 163.0)	115	0.97	0.80–1.16	13	1.89	1.00–3.22	97	0.84	0.68–1.03	7	1.44	0.58–2.97
Connective tissue (171)	3	0.85	0.17–2.48	3	7.20	1.48–21.0	1	0.32	0.01–1.79	0	–	–
Breast (174–175)	1	1.42	0.04–7.89	11	0.89	0.44–1.59	0	–	–	12	1.29	0.67–2.25
Prostate (185)	111	1.14	0.93–1.37	0	–	–	104	1.01	0.82–1.22	0	–	–
Bladder and other urinary organs (188, 189.3–4, 189.8–9)	25	1.15	0.74–1.70	0	–	–	22	0.97	0.61–1.48	1	1.33	0.03–7.40
Kidney (189.0–2)	24	0.89	0.57–1.33	0	–	–	22	0.84	0.53–1.27	2	1.21	0.15–4.38
Brain (191–192)	20	0.93	0.57–1.44	1	0.46	0.01–2.57	18	0.98	0.58–1.58	2	1.27	0.15–4.60
Non-Hodgkin lymphoma (200, 202)	21	1.00	0.62–1.53	3	1.54	0.32–4.49	11	0.56	0.28–1.01	0	–	–
Multiple myeloma (203)	12	0.89	0.46–1.55	0	–	–	14	1.04	0.57–1.74	0	–	–
Leukemia (204–208)	13	0.54	0.29–0.93	2	0.94	0.11–3.40	29	1.26	0.84–1.80	2	1.19	0.14–4.30

Standardized mortality ratios (SMR) by site of cancer (ICD-9), main mill pulping process and gender. Observed deaths (O) and 95% confidence intervals (CI) are given

cancer mortality was increased among the female workers (SMR 1.70, 95% CI 1.04–2.63), especially those in the sulfate mills, but there was no increase among the male workers (SMR 0.91, 95% CI 0.79–1.04). Sulfite mill workers did not have increased risks of lung cancer (SMR 0.87, 95% CI 0.71–1.08) or stomach cancer (SMR 1.07, 95% CI 0.84–1.36). Females working in the sulfate mills also showed an increased mortality from connective tissue malignancy, with an SMR of 7.20 (95% CI 1.48–21), based on only three cases from the same mill, but different departments. The risk estimates generally tended to decrease when analyses were restricted to workers employed for 20 years or more (data not shown). However, there was a minor raise in the risk from stomach cancer among these workers, with an SMR of 1.15 (95% CI 0.92–1.42), based on 86 observed cases compared to 1.01 (95% CI 0.84–1.20), based on 129 observed cases among all the workers.

Cancer mortality by department is presented for males in Table 4 and for females in Table 5. There was no increased mortality from brain tumors, and the risk estimates by department ranged from SMR 1.51 among male sulfate pulping workers to SMR 0.63 among male sulfite pulping workers. However, increased risks for lung cancer associated with work in the paper production departments (SMR

Table 4 Cancer mortality among Swedish male pulp and paper mill workers

Site of cancer (ICD-9)	Wood preparation males (n = 1,354)			Sulfate pulping males (n = 1,809)			Sulfite pulping males (n = 1,886)			Maintenance males (n = 4,540)		
	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI
All malignancies (140–208)	130	0.87	0.73–1.03	117	0.91	0.75–1.09	141	0.89	0.75–1.05	339	1.05	0.94–1.17
Stomach (151)	8	0.54	0.23–1.05	17	1.35	0.79–2.17	17	1.15	0.67–1.83	33	1.11	0.77–1.56
Intestine (152–154)	20	1.09	0.67–1.68	9	0.57	0.26–1.08	21	1.10	0.68–1.68	44	1.13	0.82–1.52
Pancreas (157)	11	1.14	0.57–2.03	8	0.95	0.41–1.88	7	0.68	0.27–1.39	18	0.85	0.51–1.35
Lung, bronchus and pleura (162, 163.0)	17	0.65	0.38–1.04	24	1.04	0.66–1.54	34	1.17	0.81–1.64	59	1.00	0.76–1.29
Prostate (185)	25	0.99	0.64–1.46	24	1.20	0.77–1.78	18	0.73	0.43–1.15	57	1.16	0.88–1.80
Bladder and other urinary organs (188, 189.3–4, 189.8–9)	2	0.40	0.04–1.33	5	1.14	0.37–2.66	5	0.91	0.30–2.12	15	1.37	0.77–2.26
Kidney (189.0–2)	6	1.00	0.37–2.17	4	0.76	0.21–1.93	5	0.76	0.25–1.78	11	0.82	0.41–1.46
Brain (191–192)	4	1.06	0.29–2.72	6	1.51	0.55–3.28	3	0.63	0.13–1.84	12	1.15	0.60–2.01
Non-Hodgkin lymphoma (200, 202)	3	0.69	0.14–2.03	2	0.50	0.43–1.63	2	0.41	0.05–1.47	14	1.34	0.74–2.27
Multiple myeloma (203)	2	0.63	0.08–2.28	1	0.37	0.01–2.07	0	–	–	6	0.89	0.33–1.93
Leukemia (204–208)	5	0.96	0.31–2.24	3	0.64	0.13–1.86	5	0.88	0.28–2.05	10	0.84	0.40–1.54

Site of cancer (ICD-9)	Paper production males (n = 3,178)			Office males (n = 1,930)			Other males (n = 4,697)			Total males (n = 18,163)		
	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI
All malignancies (140–208)	145	0.96	0.81–1.12	145	0.90	0.76–1.06	304	0.96	0.86–1.08	1,226	0.95	0.90–1.01
Stomach (151)	16	1.19	0.68–1.94	14	0.92	0.50–1.54	29	0.98	0.66–1.41	124	1.02	0.85–1.22
Intestine (152–154)	17	0.94	0.55–1.50	14	0.72	0.39–1.20	39	1.02	0.73–1.39	154	0.99	0.84–1.15
Pancreas (157)	13	1.31	0.70–2.23	8	0.77	0.33–1.51	18	0.87	0.52–1.38	78	0.93	0.73–1.16
Lung, bronchus and pleura (162, 163.0)	19	0.68	0.41–1.06	30	1.03	0.70–1.48	48	0.84	0.62–1.11	212	0.91	0.79–1.04
Prostate (185)	27	1.24	0.82–1.81	33	1.28	0.88–1.80	48	0.98	0.72–1.30	215	1.07	0.93–1.22
Bladder and other urinary organs (188, 189.3–4, 189.8–9)	7	1.42	0.57–2.92	5	0.89	0.29–2.07	12	1.11	0.57–1.94	47	1.06	0.78–1.41
Kidney (189.0–2)	4	0.63	0.17–1.62	3	0.46	0.09–1.34	18	1.38	0.82–2.18	46	0.87	0.63–1.16
Brain (191–192)	5	0.90	0.29–2.10	4	0.86	0.23–2.19	10	1.00	0.48–1.84	38	0.95	0.67–1.31
Non-Hodgkin lymphoma (200, 202)	5	0.98	0.32–2.29	3	0.61	0.13–1.77	4	0.40	0.11–1.02	32	0.79	0.54–1.12
Multiple myeloma (203)	5	1.60	0.52–3.72	4	1.18	0.32–3.03	9	1.36	0.62–2.58	26	0.96	0.63–1.41
Leukemia (204–208)	4	0.69	0.19–1.77	5	0.87	0.28–2.03	12	1.03	0.53–1.80	42	0.89	0.64–1.21

Standardized mortality ratios (SMR) by site of cancer (ICD-9) and department. Observed deaths (O) and 95% confidence intervals (CI) are also given

2.81, 95% CI 1.40–5.03), and pancreas cancer in the office departments (SMR 2.90, 95% CI 1.16–5.97), were detected among the female workers.

Cancer mortality was also analyzed within different time periods (data not shown in tables), and the results showed that 15% of the malignant deaths occurred between 1952 and 1971, 52% between 1972 and 1991, and 33% between 1992 and 2001. In addition, a few new significant associations appeared when these data were analyzed department-wise. These were increased risks of rectal cancer among the male wood preparation workers between 1992 and 2001 (SMR 3.31, 95% CI 1.08–7.73, 5 cases), stomach cancer during 1952–1971 (SMR 2.08, 95% CI 1.00–3.82, 10 cases) and lung cancer during 1992–2001 (SMR 1.89, 95% CI 1.03–3.16, 14 cases) among males working in sulfate pulping departments, and prostate cancer among male maintenance workers during 1972–1991 (SMR 1.60, 95% CI 1.14–2.19, 39 cases).

Among workers in the steam and power generation department (227 male employees, 5,906 person-years, with 66 deaths), there was a no significant increase in deaths due to cancer of the pancreas (SMR 2.73, 95% CI 0.56–7.97 based on three observed cases; data not shown in tables).

Table 5 Cancer mortality among Swedish female pulp and paper mill workers

Site of cancer (ICD-9)	Paper production females (*n* = 570)			Office females (*n* = 822)			Other females (*n* = 721)			Total females (*n* = 2,290)		
	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI	O	SMR	95% CI
All malignancies (140–208)	42	1.02	0.73–1.38	34	0.92	0.64–1.28	29	0.87	0.58–1.24	114	0.95	0.78–1.14
Stomach (151)	1	0.47	0.01–2.61	1	0.54	0.01–3.01	3	1.78	0.37–5.20	5	0.82	0.27–1.91
Intestine (152–154)	3	0.61	0.13–1.79	2	0.48	0.06–1.72	4	1.03	0.28–2.65	9	0.65	0.30–1.23
Pancreas (157)	2	0.72	0.09–2.61	7	2.90	1.16–5.97	2	0.91	0.11–3.30	12	1.52	0.78–2.65
Lung, bronchus and pleura (162, 163.0)	11	2.81	1.40–5.03	4	1.08	0.29–2.75	4	1.19	0.33–3.06	20	1.70	1.04–2.63
Breast (174–175)	9	1.23	0.56–2.33	6	0.88	0.32–1.91	7	1.14	0.46–2.35	23	1.06	0.67–1.59
Bladder and other urinary organs (188, 189.3–4, 189.8–9)	0	–	–	0	–	–	1	2.19	0.06–12.2	1	0.60	0,02–3,34
Kidney (189.0–2)	1	0.77	0.02–4.28	0			0	–	–	2	0.54	0,06–1,94
Brain (191–192)	0	–	–	2	1.67	0.20–6.02	1	0.93	0.02–5.18	3	0.80	0.17–2.35
Non-Hodgkin lymphoma (200, 202)	2	1.68	0.20–6.08	0	–	–	0	–	–	3	0.87	0.18–2.55
Multiple myeloma (203)	0	–	–	0	–	–	0	–	–	0	–	–
Leukemia (204–208)	2	1.53	0.19–5.54	0	–	–	1	0.93	0.02–5.15	4	1.05	0.29–2.69

Standardized mortality ratios (SMR) by site of cancer (ICD-9) and department. Observed deaths (O) and 95% confidence intervals (CI) are also given

We wanted to use a rural population as a reference since most of the pulp and paper mills were situated in rural areas, and this was possible based on available data from 1970. As expected, the risk estimates increased when a rural population was used as a reference, although the increases were marginal. The SMR for all malignancies increased from 0.99 to 1.03 for all the male workers (data not shown).

Discussion

This study of cancer mortality in a Swedish cohort study showed an increased risk for lung cancer among female pulp and paper mill workers, especially among those working in the paper production departments, and for pancreas cancer among office working females. There were no other significant department-specific increases in risks, and no increases in brain tumor mortality. Neither any lung nor stomach cancers associated with employment in sulfite pulping departments were detected. However, among female workers in sulfate mills, there was an increased mortality from sarcoma.

The advantages of this study were the size of the cohort and the long follow-up period, which provided abundant number of cases for analysis. Indeed, with the exception of the IARC merged cohort, this is one of largest pulp and paper mill mortality studies. Furthermore, the Scandinavian countries are known for their high quality mortality and cancer registers. However, as in many other cohort studies, no information was available on the individuals' potential lifestyle confounders, such as smoking, which is an obvious disadvantage. When analyzing multiple outcomes, as is usually done in cohort studies, there should always be concern about random significances; some of the reported results could be due to chance.

The overall mortality in the cohort was lower than in the reference population, despite an increased mortality from acute myocardial infarction among males in both the sulfate and sulfite mills (Andersson et al. 2007), and there was no increase in mortality from malignancies. These findings are in accordance with the "healthy worker survival effect" (HWSE) often observed in industrial cohorts, resulting in lower total mortality among them than in the general population (Checkoway et al. 2004). Furthermore, long-term workers tend to be healthier than average, and thus the inclusion of workers hired before the start of the follow-up period may exaggerate the HWSE (Applebaum et al. 2007). However, most studies include such workers to gain statistical power and, while we analyzed the cohort for all the malignancies; without them the results were not overly affected, and hence we decided to retain them (all males SMR 0.95, 95% CI 0.90–1.01, 1,226 cases; excluding males hired before follow-up SMR 0.95, 95% CI 0.86–1.03, 481 cases; all females SMR 0.95, 95% CI 0.78–1.14, 114 cases; excluding females hired before follow-up SMR 1.01, 95% CI 0.80–1.25, 80 cases). In addition, while it would have been preferable to use a rural population as a reference, it was not possible before 1970, and doing so probably would not have changed the results considerably.

We wanted to study brain tumor mortality by department as increased risks have been found in relation to sulfite mills (Band et al. 1997; Andersson et al. 1998), sulfate mills (Andersson et al. 2001), paper production (Szadkowska-Stanczyk et al. 1998), and maintenance workers (Andersson et al. 2002), although no causative exposure agent has been identified as yet. Brain tumor mortality was not increased in this present study. Previously reported risk excesses in Sweden were of gliomas, which are usually fatal, thus any significant increase in them should be detectable in a mortality study of this kind.

Many other studies have found increased risks for lung cancer among pulp and paper mill workers, with asbestos, sulfur dioxide as well as sulfite pulping among the suggested causal exposures (Torén et al. 1996b; Band et al. 1997, 2001; Henneberger and Lax 1998; Langseth and Andersen 2000; Carel et al. 2002; Lee et al. 2002). One study also found mill workers exposed to organochlorine compounds to have an increased risk for lung cancer (Jäppinen and Pukkala 1991), but IARC analyses of organochlorine compounds among pulp and paper mill workers could not confirm these findings (McLean et al. 2006). In a Norwegian cohort of female, pulp and paper mill workers exposure to asbestos has been proposed (Langseth and Kjaerheim 2004). The short term workers in the cited cohort had an increased lung cancer incidence but no pleural mesothelioma (Langseth and Andersen 1999). We found increased lung cancer mortality among female paper department workers but not in male workers (except during 1992–2001 for sulfate pulping departments which could be a chance finding). Sulfite mill workers exposed to sulfur dioxide did not have increased risk. In this present study, mortalities due to mesothelioma (15 cases among males but none among females) were also included in the lung cancer mortalities, as they were not separated in the reference data. These findings indicate that the males may have been exposed to asbestos, but the overall rate of lung cancer mortality among males was not increased.

Is the increased lung cancer mortality among female paper production workers observed in the presented Swedish cohort due to chance, confounding or exposure? Smoking could not be adjusted for in our cohort, but that would probably not explain the increased mortality from lung cancer. Confounding effects could generally only account for small risk increases (Kriebel et al. 2004; Blair et al. 2007) and although smoking habits are unlikely to have differed greatly between departments, female workers in the other departments showed no increased lung cancer risk. Asbestos has been used as filler in paper production, as an insulation material in the mill, and in the brake shoes of slitting machines. In respect of asbestos, there was no pleural mesothelioma cases. Peritoneal mesothelioma can be misdiagnosed as pancreatic cancer, but there was no increase of this condition among the female workers in the paper department either. Certainly, there were few female workers. In addition, there is no obvious exposure risk in the mills that can explain why the female workers, but not the males, were at increased risk of lung cancer. One possibility is that the female workers might have had to work in a dustier environment than the male workers. This possible difference between working conditions may have been more likely after the introduction of control rooms for the paper machines in recent years, since female workers often have jobs other than operating the paper machines in the paper department. Furthermore, exposure to dust containing inorganic substances, such as kaolin, lime, cement, brick, and grindstone, appeared to be associated with an increased risk for lung cancer (adjusted for smoking) in a Polish pulp and paper mill cohort (Szadkowska-Stanczyk et al. 2001). Accordingly, silica-containing dust measurements exceeding the OEL were recorded in the paper departments' database entries in this present study, suggesting potentially high concentrations of crystalline silica, classified as a carcinogen by IARC.

As stomach cancer has been associated with sulfite pulping and this being a fairly big cohort regarding sulfite mill workers, stomach cancer was one of the issues of interest (Torén et al 1996b). However, the same could not be confirmed in this cohort; if there was any increase, it was among sulfate pulping male workers during 1952–1971.

In the cohort analyses we find some increased mortalities of cancer that could be due to chance which, however, needs further discussion. Besides smoking, few risk factors are known for pancreatic cancer, although a few other reports of increases in pancreatic cancers among pulp and paper mill cohort studies from several departments have been published (Band et al. 2001; Wild et al. 1998). The female office workers showed increased mortality from pancreatic cancer but no increases in lung cancer mortality, suggesting that they did not smoke any more than the general population, although the group studied was too small to draw firm conclusions. However, some of the office workers might previously have been located in the production departments, where they might have had been exposed to more risk agents. Conversely, this finding could be random, since multiple outcomes were studied and many analyses were performed. This could also be the case for the findings regarding different cancer forms in just one of the three time periods analyzed. An alternative possibility is that our findings reflect differences in exposure over time.

Nonvolatile organochlorine compounds have been suggested as a risk factor for soft-tissue sarcoma (McLean et al. 2006). Previously reported exposures to, and biological measurements of, nonvolatile organochlorine compounds in pulp mills and workers have been low, although it has been reported that the compounds measured in a bleaching plant were present in higher concentrations than expected (but still low) among the bleachery workers there (Rosenberg et al. 1995). No association between soft-tissue sarcoma and exposure to organochlorine compounds was reported in an analysis of the IARC-merged pulp and paper mill cohort data (McLean et al. 2006). Most cohort studies do not report soft-tissue sarcomas, since they can emerge in various organs and thus are difficult to study. However, in a recently published case–control study the incidence of soft-tissue sarcoma was found to be increased in short-term pulp and paper mill workers (Hussain et al. 2007). The increased risk of malignancy in connective tissue in the present cohort study, suggestive of soft-tissue sarcoma, was based only on three female cases from the same sulfate mill. All of these individuals worked during the 1970s having worked for several years, but there was no obvious common exposure across the three cases. However, all the seven cases of connective tissue malignancy had worked in mills that performed chlorine-based bleaching, thereby potentially exposing them to nonvolatile organochlorine compounds, but none of these cases was identified as working in the bleachery departments.

Analysis of carcinogen exposures, based on our measurement database, indicated that both the qualitative and quantitative patterns of various agents differed amongst departments. Exposure in this present cohort study was assessed departmentwise and could be subject to misclassification. However, many of the workers were skilled, so changes in jobs were more likely to have occurred within, than between departments. Exposure misclassification in this study was regarded as nondifferential. Exposure measurement data from Swedish pulp and paper mills before 1970 were sparse, and many of the employment years of male workers were obtained from that time period. However, systematic changes in production and ventilation facilities were mostly made from the mid 1970s and throughout the 1980s. This suggests that air concentration levels recorded in the early 1970s were probably similar to those prevailing in the work environment during the 1950s and 1960s.

In conclusion, the chemical exposure profiles in pulp and paper mills are complex in terms of both the diversity of species involved and their distribution, which complicates exposure and risk assessments. Hence, even when an increased risk is identified in a given department, it will often be difficult to identify the causal exposure agent. In our study, sparse number of quantitative retrospective exposure measurements makes it difficult to assess exposure–response relationships for a particular agent and effect. Nevertheless, it is important to identify any department that is at increased risk. This would allow general preventive measures such as substitution, elimination, or reduction of chemicals identified at particular departments.

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